132899

HIGH RESOLUTION INFRARED RADIATION SOUNDER

FOR THE

NIMBUS F SPACECRAFT

(NASA-CR-132899) HIGH RESOLUTION INFRARED RADIATION SOUNDER FOR THE NIMBUS F SPACECRAFT Quarterly Report, Apr. - Jun. 1973 (ITT Aerospace/Optical Div.) 42 p HC $4.25 CSCL 14B G3/14

N74-15099

Unclas
27003

E.W.Koenig, et. al.

ITT Aerospace/Optical Division
3700 E. Pontiac Street
Fort Wayne, Indiana 46803

Revised September 1973

Quarterly Report for Period April - June, 1973

Prepared for

National Aeronautics & Space Administration
Goddard Space Flight Center
Greenbelt, Maryland 20771

Contract # NAS5-21651

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle HIGH RESOLUTION INFRARED RADIATION SOUNDER FOR THE NIMBUS F SPACECRAFT		5. Report Date September, 1973
		6. Performing Organization Code
7. Author(s) E. W. Koenig, et. al.		8. Performing Organization Report No.
9. Performing Organization Name and Address ITT-Aerospace/Optical Division 3700 E. Pontiac St. Fort Wayne, Indiana 46803		10. Work Unit No.
		11. Contract or Grant No. NAS5-21651
12. Sponsoring Agency Name and Address National Aeronautics & Space Admin. Goddard Space Flight Center Greenbelt, Maryland 20771 Bertrand Johnson, Technical Officer		13. Type of Report and Period Covered Quarterly April-June 1973
		14. Sponsoring Agency Code
15. Supplementary Notes		

16. Abstract The period of this report, April-May-June 1973, was one of concentrated activity to assemble the HIRS Engineering Model. The unit has been completely assembled and bench tested. Vacuum chamber tests have been initiated and will be completed in the next period.

Several design changes have been incorporated in the HIRS as a result of tests. These improvements relate to an increase in the reliability of operation of the scan mirror and data processing.

Prototype component design is complete, with parts on order and in fabrication. A schedule of Prototype activity is included in the report.

17. Key Words	18. Distribution Statement
Optics Step Scan Amplifiers Radiant Coolers	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified		

ABSTRACT

The period of this report, April-May-June 1973, was one of concentrated activity to assemble the HIRS Engineering Model. The unit has been completely assembled and bench tested. Vacuum chamber tests have been initiated and will be completed in the next period.

Several design changes have been incorporated in the HIRS as a result of tests. These improvements relate to an increase in the reliability of operation of the scan mirror and data processing.

Prototype component design is complete, with parts on order and in fabrication. A schedule of Prototype activity is included in the report.

TABLE OF CONTENTS

		Page
1.0	INTRODUCTION	1-1
2.0	GENERAL	2-1
2.1	Highlights	2-1
2.2	Visits and Trips	2-1
2.3	Technical Review	2-3
3.0	SYSTEM DESIGN STATUS	3-1
3.1	Optics	3-1
3.2	Radiant Cooler	3-1
3.3	Electrical Design	3-1
3.4	Mechanical Design	3-5
4.0	EQUIPMENT STATUS	4-1
4.1	Engineering Model	4-1
4.2	Protoflight and Flight Model	4-2
4.3	Support Equipment	4-3
5.0	NEW TECHNOLOGY	5-1
6.0	PROGRAM FOR THE NEXT INTERVAL	6-1
7.0	SCHEDULES	7-1
7.1	Engineering Model	7-1
7.2	Protoflight Model	7-1
8.0	CONCLUSIONS	8-1
9.0	RECOMMENDATIONS	9-1
Appendix I	HIRS MIRROR SCAN SYSTEM	I-1

1.0 INTRODUCTION

This report covers the period of April through June, 1973. The major events occurring during this period were the assembly and test of the Engineering Model. Operation of the Engineering Model in laboratory ambient, bench cooled and vacuum chamber conditions have taken place during this period. Many of these tests were witnessed by NASA and NOAA personnel.

Schedules of Engineering Model and Prototype Model are included in this report.

2.0 GENERAL

2.1 Highlights

System definition of the prototype model has been changed to Protoflight, with the attendant change in test procedure.

The Engineering Model has been completely assembled and tested in its full configuration. A preliminary performance test in vacuum indicated several areas of improvement. Another test early in the next period will be made prior to shipment to General Electric for integration tests.

A technical review at ITT on April 30 and May 1 resulted in significant interchange of knowledge and a few changes in design and test direction.

Procurement of electronic components continues to limit the scheduling of Protoflight activity, although the continuing test activity on Engineering Model also restricts the early release of Proto wiring and assembly tasks.

2.2 Visits and Trips

The program manager participated in Nimbus F manager's reviews at NASA on April 24 and on June 27.

A Nimbus Technical Review Committee met at ITT on April 30 and May 1 to consider design approach, design changes, interface definitions and program plans. A summary of this meeting is given in the report for May and is updated in this report.

Other trips made by ITT personnel are listed in the Trip Summary.

Mr. Ron Pownall, HIRS Optics Manager at Ferson Optics, visited ITT on May 24 to discuss optics test procedures and review a blemish in the PM optics.

TRIP REPORT

Date	Vendor	Location	ITT	Purpose
Apr. 2	Computer Devices	Santa Fe Springs	Smith	Motor Test Program
Apr. 3	Micro Semiconductor	Santa Ana	Smith	Construction Analysis
Apr. 4, 6	Electro Nuclear Labs	Burlingame	Smith	Pre-Cap Visual, Capping
Apr. 5	National Semiconductor	Santa Clara	Smith	Quality Changes
May 3	Schaeffer Magnetics	Chatsworth	Smith	Motor Revisions
May 8, 10	Computer Devices	Santa Fe Springs	Smith	Motor Test Review
May 9	Litton Systems	Chatsworth	Smith	Encoder Acceptance
May 14	Micro Semiconductor	Santa Ana	Smith	Pre-Cap Visual
May 15, 18	Electro Nuclear Labs	Burlingame	Smith	Test Witnessing
May 16	Ferson Optics	Ocean Springs	Whitacre	Quality Review
May 30	Surface Finishes	Addison	Smith	Source Inspection
June 6	Micro Semiconductor	Santa Ana	Smith	Pre-Cap Inspection
June 7	RCA	Findlay	Myers	Quality Survey
June 7	Electro Nuclear Labs	Burlingame	Smith	Final ATP
June 11	ITT Cannon	Phoenix	Smith	Connector Specs

2.3 Technical Review

An informal review of HIRS designs was held at ITT on April 30 and May 1. This is reported in the monthly report for May. This report will present the results of the action items to date.

Persons Attending:

NASA	ITT
Joe Arlauskas, Hd., Review Comm.	Ed Koenig
Bert Johnson, HIRS T.O.	Dick Annable
Andy McCulloch, HIRS P.I.	Ed Bick
Harold Schnurr, Nimbus Q.A.	John Levick
Dan Schwartz, G.E. Interface	Dave Melton
Chuck Thienel, Mech. Systems	Phil Murray
Casey deKramer, Electro-Mech.	Bud Smith
Bernie Johnson, Electronics	Martin Rust
Joe Deskewitz, Analysis	
Tom Anderson, Electronics	Paul Roberts, DCAS

2.3.1 Visible Channel Isolators

Determine what is required to separate the visible channel operation from IR operation in the event of cooler failure.

No action required. The visible channel operates independently of cooler operation. The filter chopper must continue to operate at synchronous speed, and the scan mirror can be scanning or stopped at nadir. An output from the visible channel will be present at each scan element position.

2.3.2 Scan Mode Telemetry

Provide capability for stripping out mirror scan position on the ground in real time.

This is an action item to G.E. and, to our knowledge, has been included in the operation plan.

2.3.3 Mirror Scan Fault TM

Determine the usefulness of telemetering the occurrence of a scan fault as indicated by the scan "re-initialization" circuit when such a fault occurs.

The recognition and memory circuits for such an indicator are difficult to implement. The effect of such a fault is detectable in the position code and line count and may be detected, if needed, from other sources. No further action required.

2.3.4 Mirror Scan Tachometer

Determine the feasibility of mounting a tachometer on the motor shaft during thermal-vacuum testing as well as ambient.

Action completed. A mount for a tachometer has been included in the EM and later units. The tachometer will be removed before launch.

2.3.5 Brush Recorders

Locate recorders to be used all during final tests to provide full system evaluation data.

No response from GSFC yet. ITT has added a GFE 8-track time sampled recorder to the BCE for EM tests. It had a failure during early tests but will be used for EM acceptance tests.

2.3.6 Bench Cooler

Determine if bench cooler can be used for pre and post vibration tests.

Discussion with GSFC personnel indicate the best plan to be electrical bench cooled tests at ITT before and after vibration. Warm tests only at the vibration facility.

2.3.7 HDRSS Input

Send Technical Directive changing voltage level output to 5.6 ± 0.2V.

Action Completed. Technical Directive 7 received.

2.3.8 Cal Inhibit

Send ITT mandatory change for cal inhibit capability.

Action in process. Change not yet received at ITT, but designs are being modified for PM and FM. No change on EM.

2.3.9 Bearing Inspection

Establish procedure for receiving bearings from ITT for cleaning, inspection and lubrication.

First set of bearings have been inspected by NASA and found generally acceptable. One set will be reviewed. Time scale for turn-around is longer than anticipated.

2.3.10 Witness Mirrors

Attach witness mirrors to instrument for contamination monitoring.

Action completed. A witness mirror attached to the EM revealed several contaminants. This will be continued for PM and FM.

2.3.11 Scan System Life Test

Request motor assembly tests to be performed in vacuum environment.

Action in process. Mechanical parts for chamber tests are being designed. Cost of liquid nitrogen for long term vacuum tests and chamber availability may limit length of such tests.

2.3.12 Window Heater

Request inclusion of window heater on cooler window and cold trap for decontamination.

Action in Process. Mandatory change request anticipated soon. Design for window heater will be included in Protoflight and Flight units.

3.0 SYSTEM DESIGN STATUS

A copy of the functional block diagram of the HIRS system is shown in Figure 3-1.

Significant design improvement in the mirror scan system has taken place in this time period. A report of this is given in Appendix I. Design of the filter chopper assembly has been changed to include a larger motor having a greater torque margin for orbital operation and potentially enough torque for synchronous operation in air. Study of the signals from the filter wheel and targets indicate need for greater emphasis on reduction of degrading characteristics in this area.

3.1 Optics

Engineering model tests on the bench cooler indicate a mis-registration between channels of 0.026 inches and an energy profile that has 97% of the included energy in a 2.2° FOV in the longwave channel and 2.0° in the shortwave channel. These factors were not obtainable with reliability at the manufacturers plant, as described in earlier reports. The test equipment has been significantly improved and is now capable of tests with uncooled detectors. These characteristics cannot be changed for the Engineering Model, but are indicative of areas of concern for the Protoflight.

3.2 Radiant Cooler

The engineering model has been tested in bench cooled operation and in the space chamber. Cooling by radiant means on the bench assembly causes the patch to reach approximately 130°K. In the space chamber, the patch temperature reached 123°K withall simulated sun loads and the actual optical port input. The lack of cooling capacity to reach 120°K is attributed to a film of diffusion oil apparently caused by chamber malfunction. The design calculations for the Engineering Model cooler are being reviewed to determine if other effects may have caused this performance. With simulated sun and earth loads not impressed, the patch reached 118°K, approximately 3°K above the anticipated margin.

3.3 Electrical Design

Testing of the Engineering Model through bench, bench cooler, and space chamber conditions has led to a number of design changes. Some of these were minor deficiencies in wiring or component positioning. Several were related to operational deficiencies and required design changes.

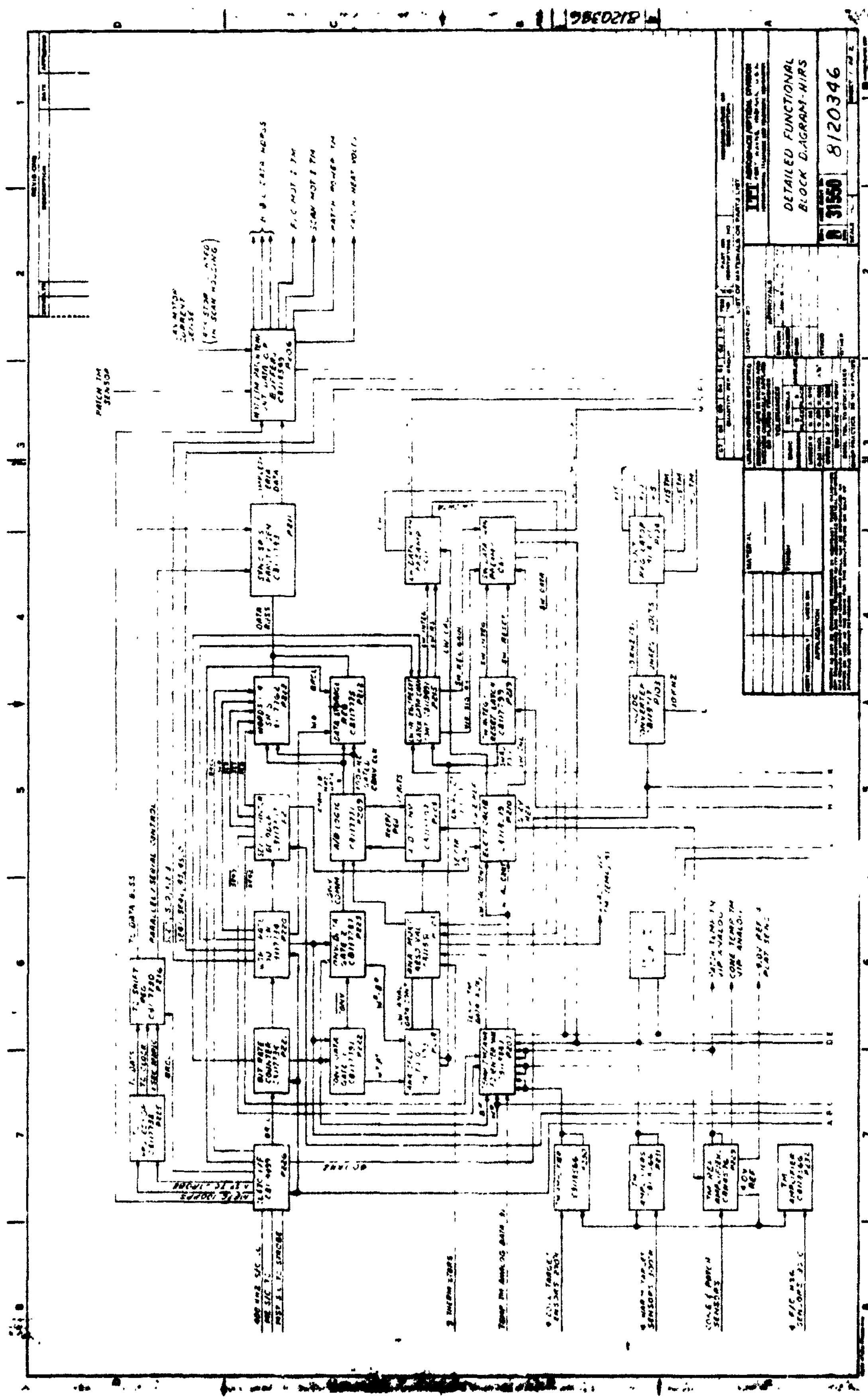


Figure 3-1

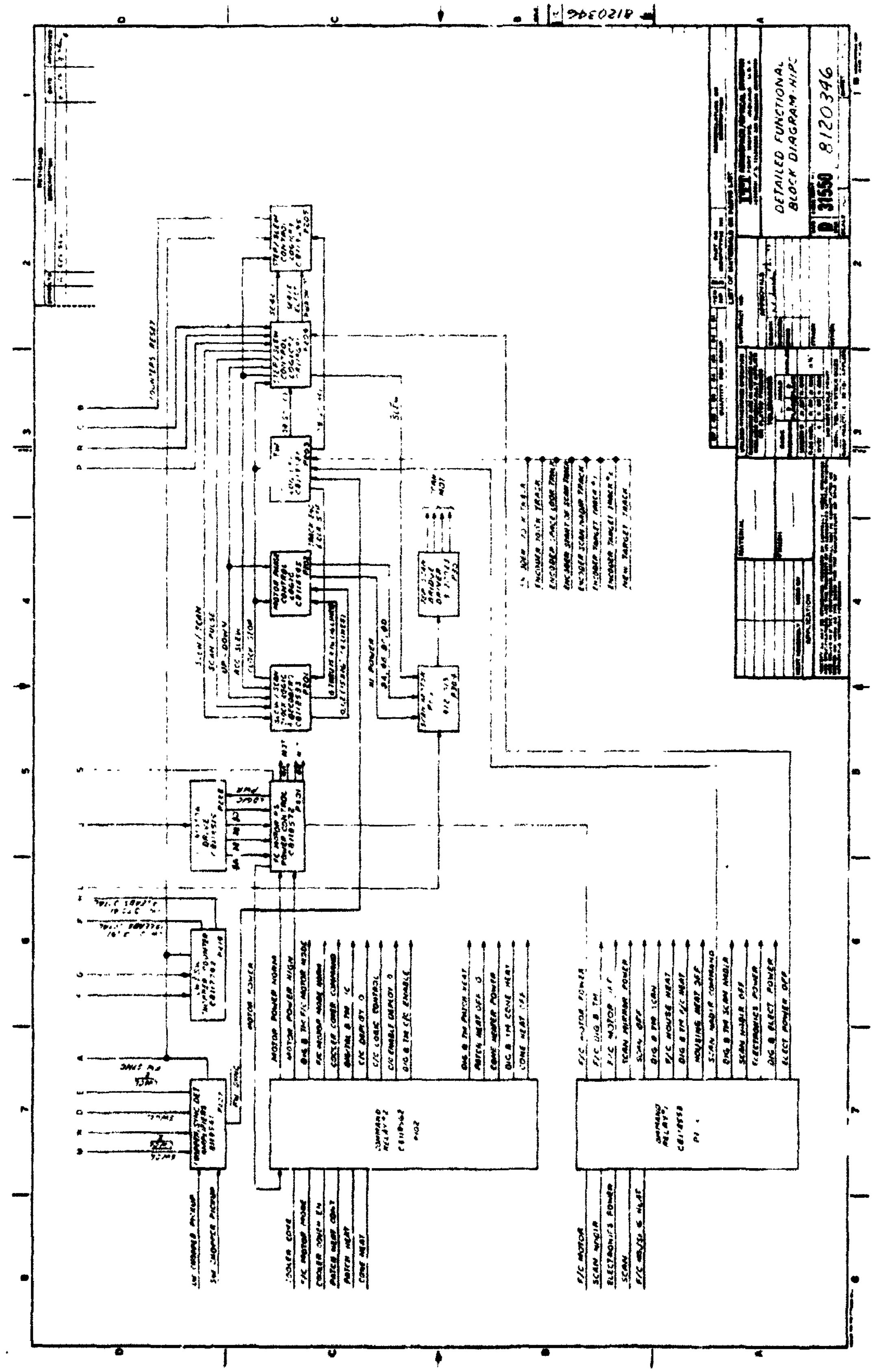


Figure 3-1 (Continued)

3.3.1 Integration Phase Control

A problem in synchronizing chopper time references to integration periods was overcome by addition of a phase correction circuit to insure that radiation from a given channel would occur when the optic field of view was fully within a filter area. To do this, a time delay of one half of a chopper opening was required. This capability was added by inserting an additional circuit board to integrate a chopper pulse interval and detect the half period of the chopper window interval. This circuit works very well and is to be incorporated in the Protoflight model. With the modification in the system, we have the proper number of full cycles of integration in each channel.

3.3.2 Scan Reference Synchronizing

The block diagram of Figure 3-1 shows the input of filter wheel sync to the word and bit counters which control the whole timing and data integration system. Initially, the filter wheel sync is required to set the system in operation. After synchronous speed is reached, the system will operate from an internal reset which is derived from counters slaved to the 100KHz clock input. We found that the original design assumed a fresh update of clock status each time the FW sync was obtained. In practice, this did not allow synchronization of the bit register clock and would not permit our printer unit to print numbers properly. The jitter in the filter wheel sync signal was enough to disturb the bi-phase logic detection circuitry, even though the time period for filter wheel rotation remained within acceptable limits. To overcome this problem, the filter wheel sync input is inhibited by a gate signal occurring at word zero and bit zero. Only when the built-up delay caused by jitter occurs outside the ±150 microsecond tolerance limits does the filter wheel have an effect. As long as the FW sync is within these bounds the word bit counter is allowed to reset by normal clock inputs with no jitter. This is completely compatible with system operation and has performed reliabily throughout the remainder of the Engineering Model tests.

3.3.3 Filter Wheel Motor Overvoltage Protection

Past design of the filter chopper power supply included a switched regulator with a voltage control to reduce driver amplifier source voltage from unregulated -24.5V to approximately -18 volts when changing from "high power" to "normal" operation. When in "high power" mode, the system was subject to a continuous overvoltage of as much as -37 volts. This high voltage level could damage the motor and the drive transistors. To alleviate this situation, the switching regulator is now kept in the circuit at all times and the output has two control conditions. During "high power" mode, the switching regulator goes to its maximum voltage output (-24V), where it is controlled by internal voltage control elements. If the power input line increases above -24V, the regulator maintains its effect and holds the output steady. This change has been included in the Engineering Model and works very satisfactorily.

3.3.4 Mirror Scan System

Tests of several types of electronic control circuits and mechanical dampers were completed during this period. Appendix I is a description of the mirror scan system and the basis of choice of the viscous damper as the most effective control of the undamped loads in the system. Although the viscous damper helps, by increasing the damping coefficient, it also suffers from the problem of low retarding force at low velocities, which is required to obtain a fully stable mirror step position. The possibility exists that a form of coulomb friction may still be required to maintain the final equilibrium condition.

Significant improvement in the electronic drive circuitry was achieved in moving from the concept of fixed series resistors in the winding circuit toward a programmed switching voltage regulator which could provide the optimum voltage levels for high power stepping and low power dwell periods. This system is described in the May monthly report.

3.3.5 Power Supply Current Limiting

As a result of a failure mode in the tests on the Engineering Model, it was decided to improve the short circuit protection of power supply regulators from short term protective systems to long term protective systems. Consequently, the regulator circuits for the plus and minus 15 volt power supply have been changed to the new configuration. In this circuit, we change from a series pass transistor with current limiting to full back current limiting. This reduces the stress on the pass transistor to one-fourth the previous and reduces stress on the converter. A third value is the significant reduction of turn on current transient.

3.3.6 HDRSS Compatibility Change

In order to conform with the anticipated data signal level requirements of HDRSS, the data system power supply was modified to include a resistor network in the five volt HDRSS regulator to set the output to 5.6 volts. This configuration is then similar to our ten volt logic regulator.

3.4 Mechanical Design

The design of the filter chopper assembly has been changed to accommodate a larger motor. Laboratory tests have shown that the motor used in the Engineering Model is unable to reach synchronous speed in air with all of the final wheel, chopper and housing features. A new motor, with increased winding stack height and core was ordered for the Protoflight Model. Data on the unit is given in Figure 3-3. The motor will be operated in high power mode in air, drawing 0.4 amperes, and consuming 10 watts. In vacuum, it will operate in a normal power mode, with a supply voltage of 16 to 18 volts, and a torque output of 2.8 oz. inches.

Alteration of several mechanical parts was necessary to permit the installation of the final motor. Housing size has not changed but the mounting plate for the motor must be changed. This does not affect the structural or thermal integrity of the system.

Design changes relating to the addition of a viscous damper required careful analysis of the added inertias, heat gain/loss and outline. All of these have been studied. The presently planned system, using viscous dampers, will greatly depend on the designs that evolve, but will probably cause an extension of the scan housing to accommodate these components.

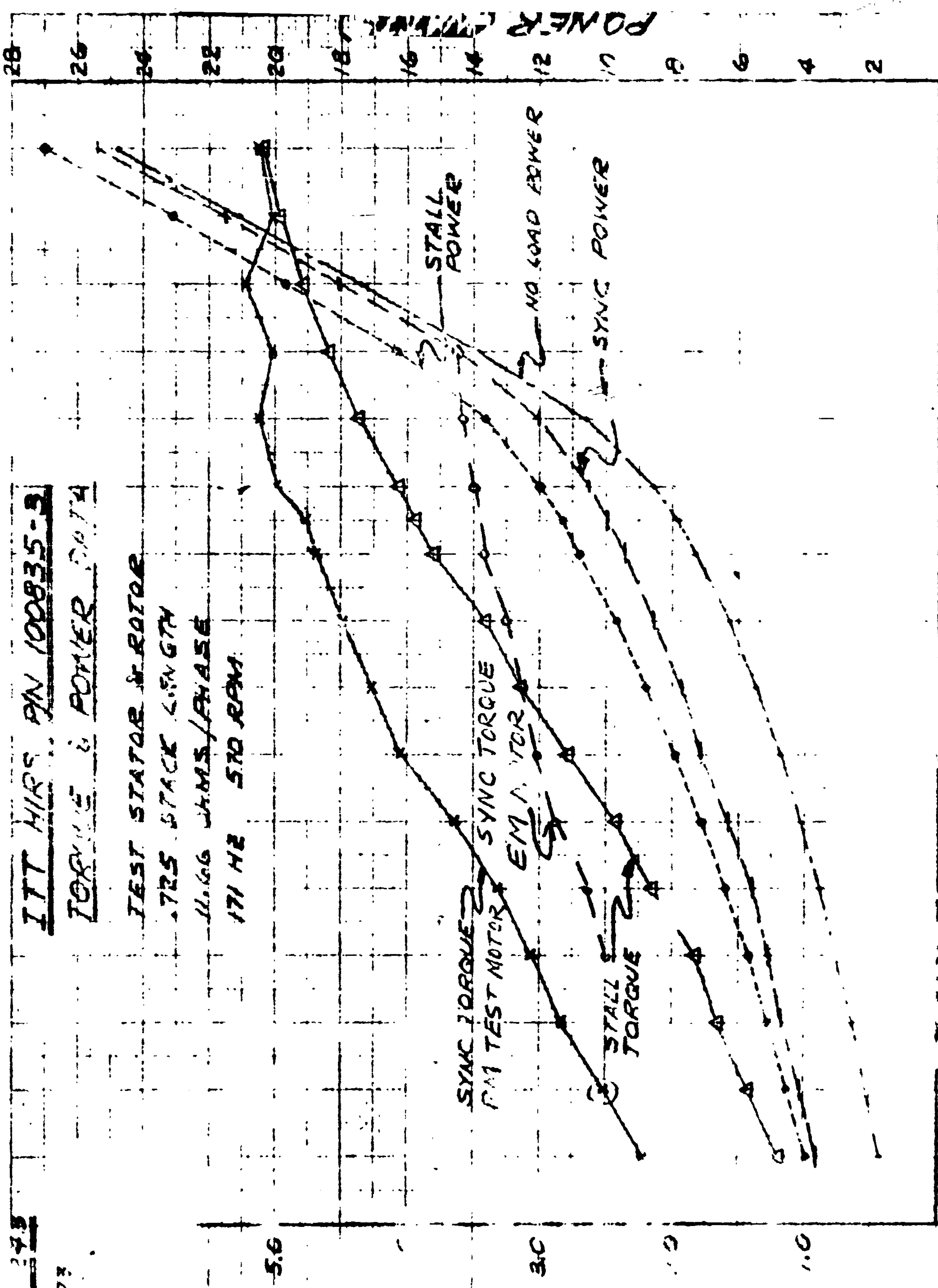


Figure 3-3: FILTER CHOPPER MOTOR CHARACTERISTICS

4.0 EQUIPMENT STATUS

4.1 Engineering Model

The engineering Model has been completely fabricated and tested in ambient conditions for all system functions. One test in the space chamber was only partly successful, indicating several deficiencies in design. All of these were corrected and the unit prepared for a final chamber run before delivery to General Electric for spacecraft integration.

4.1.1 Electrical

All circuits are operating in the Engineering Model. Test activity has required slight changes to a number of circuits. Both preamplifiers have been modified to increase signal output and reduce transient noise levels. No really effective means of eliminating the effect of web signals in the long wave amplifier have been formulated, but the effect has been reduced significantly by gating the amplifiers off during the transition period.

The integration phase control circuit was probably the greatest design change. A breadboard circuit was constructed and mounted in the warm target cavity. All other circuit changes were made on the board in question.

4.1.2 Mechanical

The assembly of the Engineering Model mechanical parts proceeded smoothly. The unit has been completely assembled and operates satisfactorily.

Early tests in the vacuum chamber with the continuous friction system had a failure in the friction unit. The polyimide brakeshoes apparently deteriorated with wear in vacuum allowing particles to build up at the edge of the brakeshoe. This caused an increase of friction to the point of nearly stopping the step motion. The polyimide material was replaced with epoxy glass material and the tests continued with no problems. It is anticipated that all tests on the Engineering Model will be with the friction brake installed.

4.1.3 Optical

Contamination of the scan mirror and optical parts from the space chamber components caused uncertainty over the effectiveness of the optics and cooler assembly. The scan mirror was cleaned chemically while the optical windows were washed with mild soap and water. The germanium windows were not touched. The decontaminating effect of warm operation in space will be assumed sufficient to clean these components.

4.1.4 Thermal

The thermal modeling of the HIRS is continuing. All nodes have been established and a data link to the IBM computer at Goddard has been tested out. Data will soon be available on this subject.

4.1.5 Weight

The Engineering Model now includes two extra circuit boards and a damper assembly since the last report. The weight of the unit is 75.4 pounds.

4.1.6 Power

The average power from the system is 20.1 watts. Operating conditions and power distribution is as follows:

Electronics	0	0	0	0
Telemetry	0.5	0.5	0.5	0.5
F/C Motor	4.4	4.4	4.4	0
Scan Motor	8.0	0	8.0	0
F/C Heater	0	1.2	1.2	0
Cooler Cone Heater	0	1.8	0	0
Cooler Housing Heater	0	10.0	0	0
	12.9	17.9	20.1	0.5 watts

The minimum satellite condition is considered a long term condition. For short periods of inactivity (30 minutes or less) the filter/chopper heater should be left on. As much as 2.5 watts might be dissipated in that unit, depending on housing temperature.

4.2 Protoflight and Flight Model

Documentation of circuit changes, wiring drawings and board layouts have been major activities during this period. Fabrication of mechanical parts, particularly those of the baseplate, optic housing, cooler assemblies and electronics module are in process. The changes to filter chopper housing for the increased motor size has not yet been completed.

Printed circuit boards for approximately half of the circuits have been fabricated. A careful check of board status versus design modifications and changes is in process.

Component procurement and expediting have been significant factors in time spent in preparation for the Protoflight unit. Substitution of part types and close liaison with vendors has helped to bring all parts to within the September 1 guideline for last received components. It is probable that some parts may yet slip beyond that date.

4.3 Support Equipment

4.3.1 Bench Check Equipment One

This unit has been inspected and delivered in place, to be used for all laboratory and space chamber tests on all models of HIRS.

4.3.2 Bench Check Equipment Two

This unit was completed and is ready for inspection and shipment direct to G.E. where it will be used with the Engineering Model and later units for integration testing.

4.3.3 Chamber Fixtures

The space chamber modifications are complete and have been used with the Engineering Model. A problem with contamination of the chamber has made the effectiveness of this particular chamber questionable. We are considering moving the HIRS unit to a larger 4 ft by 6 ft chamber.

4.3.4 Integration Targets

Consideration is being given for using the HIRS Earth Target in the space chamber at G.E. for final system tests. This will be dependent on equipment shecules and the availability of the target.

4.3.5 Life Test Equipment

Plans are in process for a greatly expanded life test program. As a result of the technical review cited earlier, the scan motor assembly, with an encoder and damper, will be tested in a chamber with the filter chopper motor. These parts will be operated in a vacuum for as long as nine months.

5.0 NEW TECHNOLOGY

No developments during this period are considered to be new technology.

6.0 PROGRAM FOR THE NEXT INTERVAL

Engineering Model chamber tests will give an indication of performance but may not be sufficient for equipment acceptance. This unit will be taken to G.E. for bench acceptance, integration, compatibility and other tests. It will be returned to ITT at the end of that period for final acceptance tests.

Fabrication of parts for the Prototype will continue and design of the video amplifiers and scan system will be completed. Assembly of the Prototype should be partly completed before the end of the next quarter.

A critical design review was held in Fort Wayne on July 19-20, for review of Prototype designs.

7.0 SCHEDULES

7.1 Engineering Model

An Engineering Model schedule in bar chart form is submitted as Figure 7-1. This is an attempt to show the broad schedule of activity performed on the Engineering Model and indicates the time periods for design, fabrication and test. During the Engineering Model activity, the designs of certain portions were fixed early in the program and have remained relatively unchanged. These are the cooler assembly, optics, scan mirror, filter wheel assembly, and basic structures. In the electronics, there are few circuits other than telemetry and some of the basic logic circuits that have not undergone some changes. Although these are normal activities in a developmental program, the new character of the HIRS techniques has caused more than a normal number of new situations during what is normally system test. The redesign effort shown in the latter stage of the program covers many of these activities.

7.2 Protoflight Model

The Protoflight and Flight model schedules are shown in several levels. Figure 7-2 is a master schedule, indicating general phasing of all of the units under fabrication at this time.

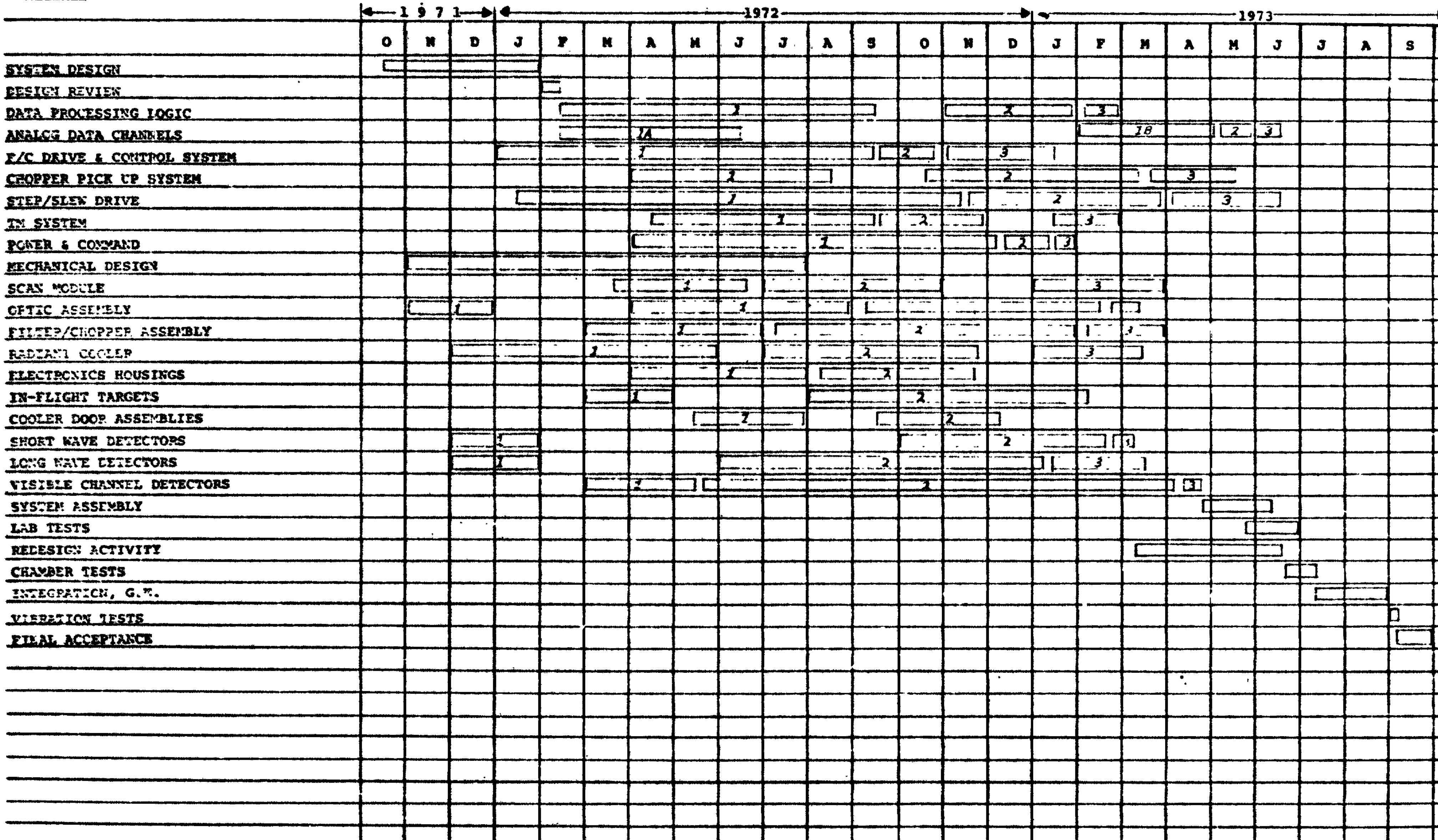
Figure 7-3 shows the Protoflight schedule in greater detail and is the plan against which we are now working. This schedule depends upon a minimal effect from ITT plant shutdown in early August, effective delivery of component parts, and a minimum of design changes as the result of design review and system tests.

The Flight Model schedule is not detailed as in Figure 7-3, but is based on continuing activity in part fabrication and assembly following the Prototype schedule by approximately two months.

ITT AEROSPACE/OPTICAL DIVISION
ELECTRO OPTICAL OPERATIONS

FIGURE 7-1
ENGINEERING MODEL SCHEDULE

1 DESIGN
2 FAB.
3 TEST



ISED BY: DATE: REVISED BY: DATE: REVISED BY: DATE:

3.9 (Rev 12/70)

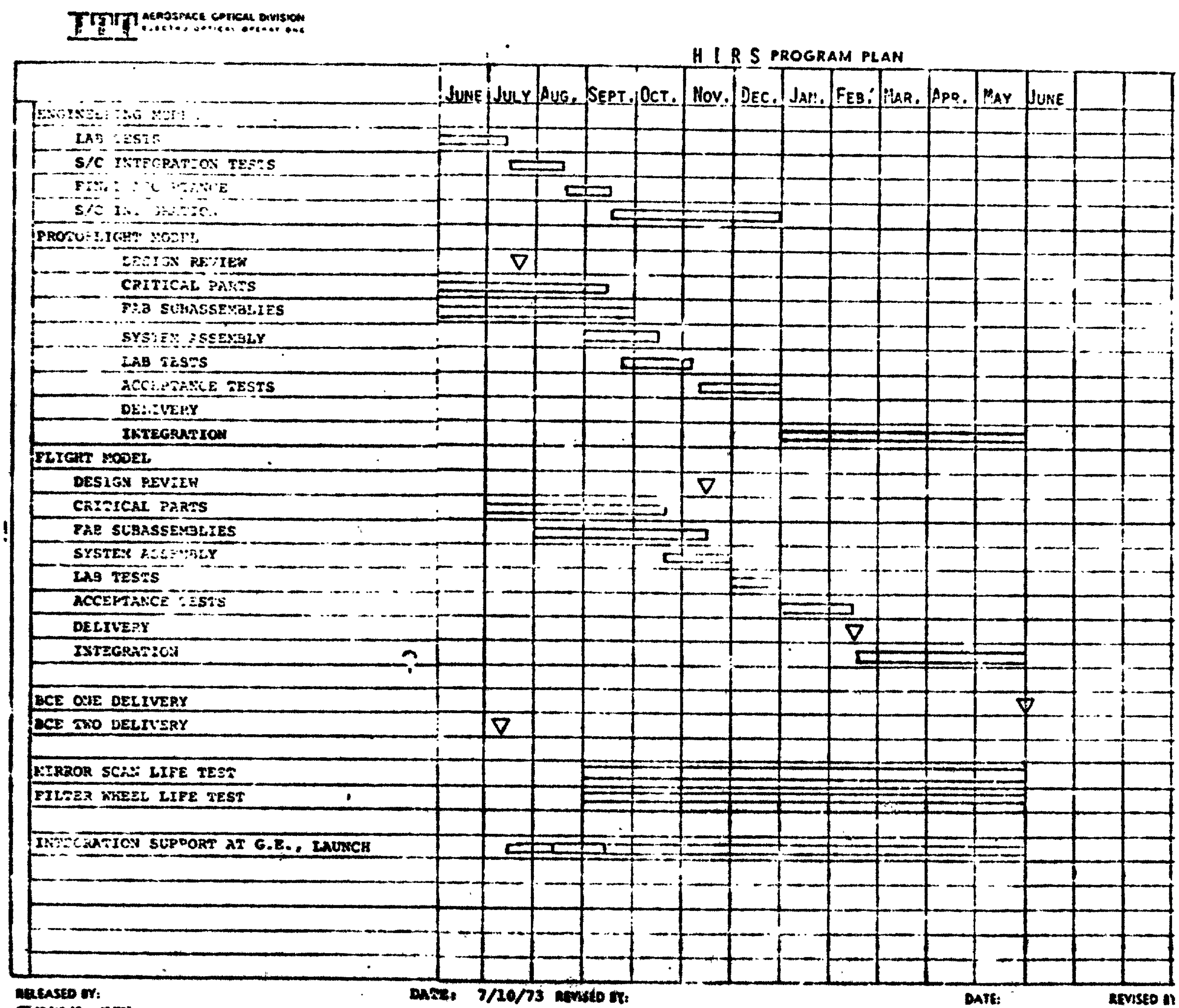


FIGURE 7-2. HIRS PROGRAM PLAN

H I R S PROTOFLIGHT PROGRAM PLAN

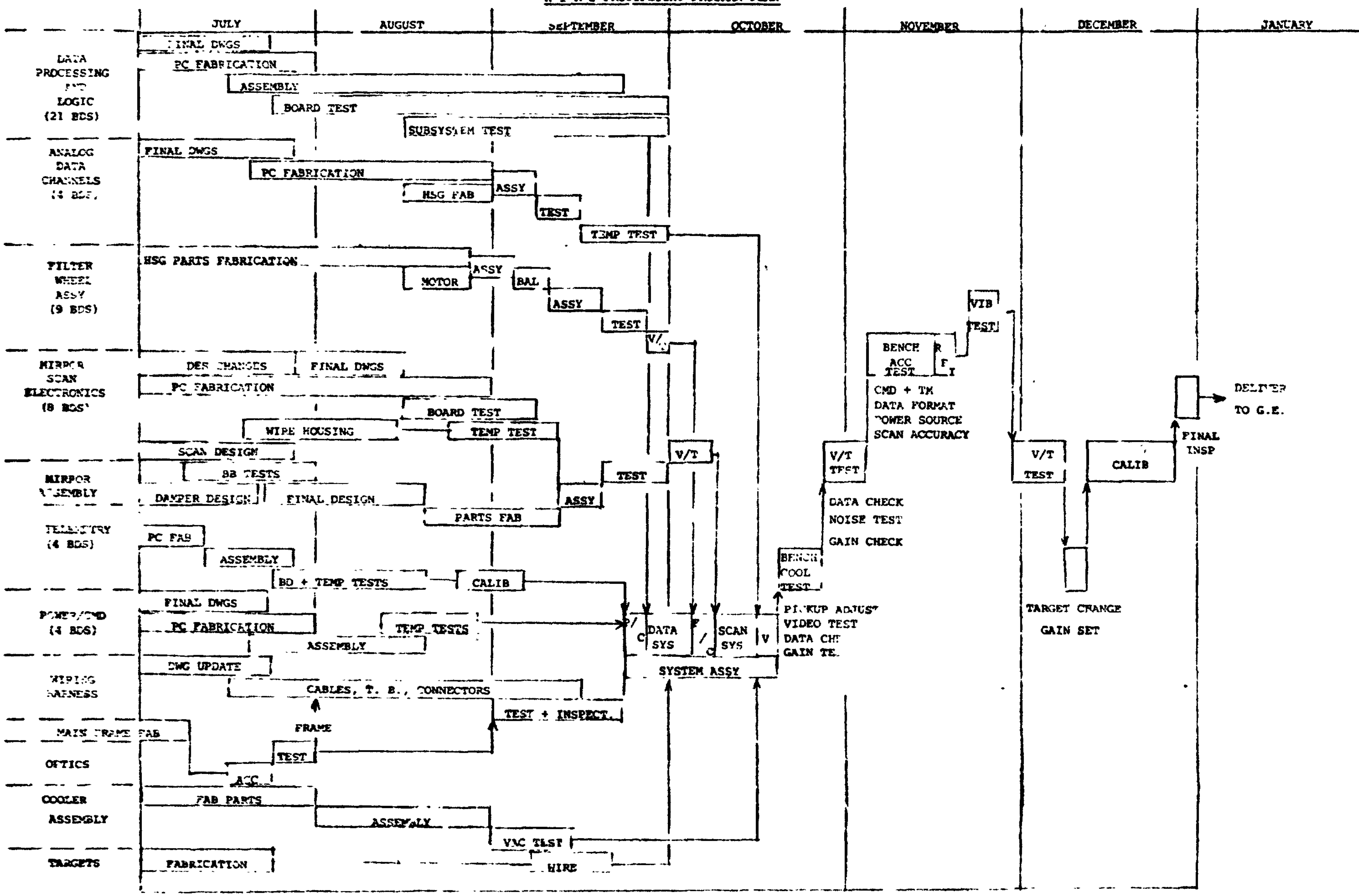


FIGURE 7-3. PROTOFLIGHT SCHEDULE

8.0 CONCLUSIONS

The results of the early tests on HIPS Engineering Model indicate satisfactory operation of the general instrument. Specific areas of concern are the mirror scan system, the analog signal amplification and processing and the filter wheel drive system. Systematic design and test activities are in process to reach conclusions in these areas as rapidly as possible.

The compressed delivery schedule of the Protoflight system continues to cause concern for the end instrument's scientific and operational integrity. The design approaches all have the appearance of solving design deficiencies and providing an instrument with the sensitivity and quality desired. A test program with time for evaluation, final optimizing, and data evaluation will probably be the loser in the race for delivery schedules.

9.0 RECOMMENDATIONS

The support of the Nimbus Technical Review Committee has been helpful in analyzing the designs and relating HIRS conditions to other programs. Even with support, it has been difficult to force developments into a fixed system delivery schedule. We recommend that the analytical support be applied as early in a program as possible, perhaps then it would be possible to evaluate some of the problems which were not obvious until nearly too late in the program for solution.

The basic HIRS technique of multiple channel sampling is expected to be a basic approach to sounders over a long time period. Perhaps a continuing study of this general approach, applied to operational spacecraft could be performed while the final tests are still in progress on the present program.

APPENDIX I

HIRS MIRROR SCAN SYSTEM

1.0 GENERAL

The pointing mirror of the HIRS system is a beryllium mirror having a 5.9 inch circular aperture on a 45° plane. It is driven by a permanent magnet stepping motor having 200 poles per revolution, 1.8° per pole. The mirror is moved to one of 42 step positions where it dwells long enough for a filter wheel to rotate, during which interval a total of seventeen spectral channels are sampled. The filter wheel rotation is controlled by a separate hysteresis synchronous motor, continuously rotating and driven from a clock controlled input. This same clock is used to derive signals for the stepper motor to insure that the step sequence takes place during an interval of filter wheel rotation when there are no filters in the optic field of view. The available time for stepping is fixed partly by this dead space interval and by the requirements for pointing accuracy and stability. One step of 1.8° must occur in a 35 millisecond timer interval. For the remainder of the 106.4 milliseconds in a step period, the pointing angle should remain fixed to ±1% of the position it reaches. This infers that the step and settling characteristics must be uniform and reliable.

After scanning the earth for a total of 42 positions (start of scan plus 41 steps) the mirror is retraced to start of scan in four step intervals. The step cycle is then repeated for twenty such scans. After the twentieth scan, the mirror is slewed to each of four positions:

a) End of Scan to Warm Target
b) Warm Target to Cold Target
c) Cold Target to Space Look
d) Space Look to Start-of-Scan

In each slew, the motion takes place in four scan element times (425 ms) then dwells for 42 element times before slewing to the next position.

Details of these scan motions are listed in Table I-1.

2.0 STEP SCAN

The method of driving the motor for step operation includes torque and retrotorque operation. During approximately one half of the step period (16 milliseconds) the next winding set is energized, tending to move the rotor to the new position. At the end of the

TABLE I-1

MIRROR SCAN PARAMETERS

Scan Element Period	106.2 milliseconds
Step	35 milliseconds
Dwell	101.2 milliseconds
Slew Time	424.8 milliseconds
Slew Angles, Retrace	73.8°
Warm Target	77.4°
Cold Target	90°
Space Look	90°
Start Scan	28.8°
Maximum Slew Rate Average	3.74 rad/sec
Motor Type	Permanent Magnet
	1.8° per step
	28 oz inches at 100 pps
	47 oz inches at stall
	Two Phase
Mirror Inertia	.08 oz. in. sec^2
Motor Bearing and Encoder Friction	.15 oz. in.
Motor Magnetic Indent Torque	1.5 oz. in.

torque period, the velocity has built up to a maximum and the momentum of the system is at a peak. At this time, the previous set of windings is energized, tending to reverse the rotor motion. Energy is therefore dissipated in slowing the rotating mass. If the retrotorque energy matches that of the torque energy, the rotation will be stopped. If these are properly balanced and timed, the motion will be precisely 1.8°. If the timing is not precise, the position error can be corrected by reapplying torque (retorque). The action may be studied by the torque versus position curves of Figure I-1. Energizing one set of windings provides equilibrium at 50 positions in the rotation, 7.2° apart. Energizing winding B only will bring the rotor to position at 1.8°, 9°, 10.8°, etc. When the physical position is near a stable position, the forward force is torque, and the reverse is retrotorque. The torque level reduces to zero at null.

In a typical situation, with the rotor stopped at the 1.8° position (Phase B energized), a pulse is applied to Phace C windings and removed from Phase B. The force increases sharply to near stall torque level, then as the rotor moves forward, the torque decreases. At the time judged to be proper for motion to be half the step distance, Phase B is energized. This retrotorque is applied for approximately an equal time period, absorb the enrgy, then be turned off. Phase C is then re-energized at a high power level, pulling the rotor to the indent position. After a short period of high power retorque, the power level is reduced for holding at the equilibrium condition.

The motion is controlled by the effective spring constants of the energized coils, the permanent magnet spring constants, and the friction in the system. The simplified diagram of Figure I-1 can be expanded to include these factors as shown in I-2. The torque at both high power level and low power (approximately .25 of high power) are both significantly above magnetic detent (47 vs 12 vs 1.5 oz in. stall torque) that the permanent magnet detent has little effect. Friction in the system is very low (.15 oz inches), causing the system to be highly underdamped. If friction were greater, the position of the rotor at end of travel would be determined by whether torque or retrotorque was in effect when the rotor position entered the friction capture zone. (An oscillation could carry the rotor through the capture zone.) The error in position could be on either side of the desired end point. It may be noted that the friction is acting against the momentum of the load and is therefore related to $\dot{\theta}$ while torque is a function of displacement or θ.

The characteristics of the motor, load, and drive system may be viewed in Figure I-3.

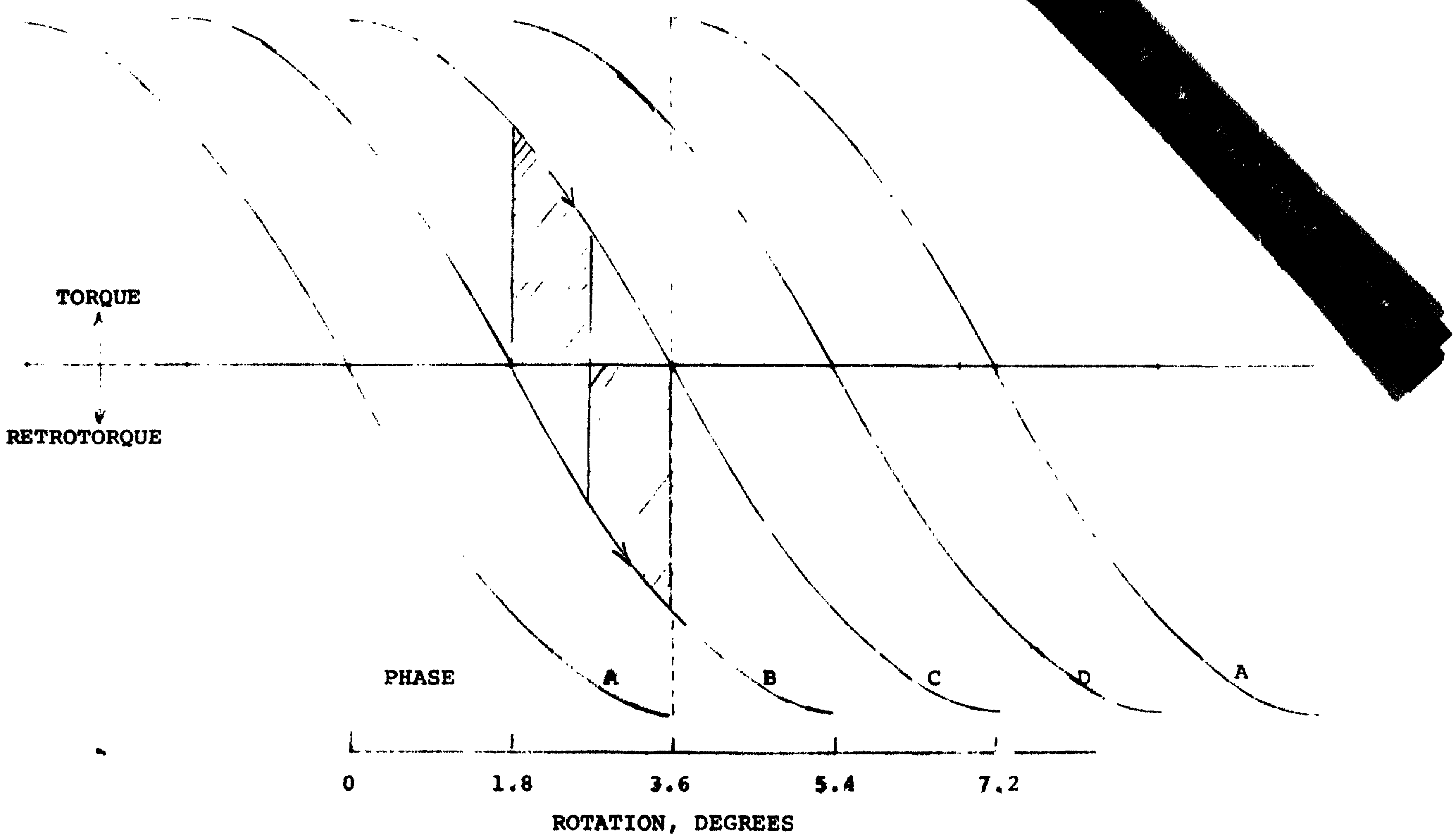


FIGURE I-1. <u>WINDING TORQUE CHARACTERISTICS</u>

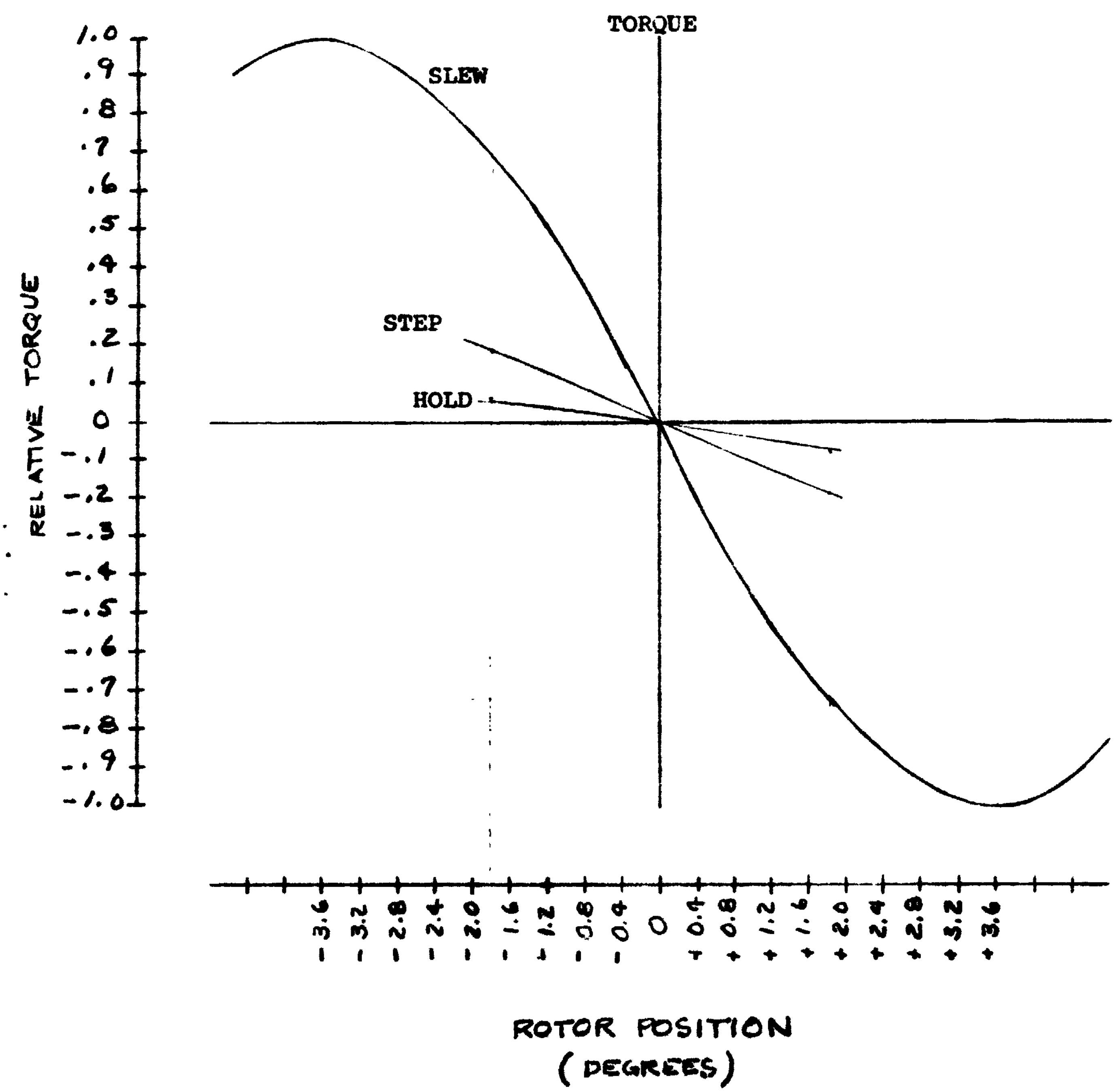


FIGURE I-2. TORQUE VERSUS POSITION OF ROTOR FROM EQUILIBRIUM

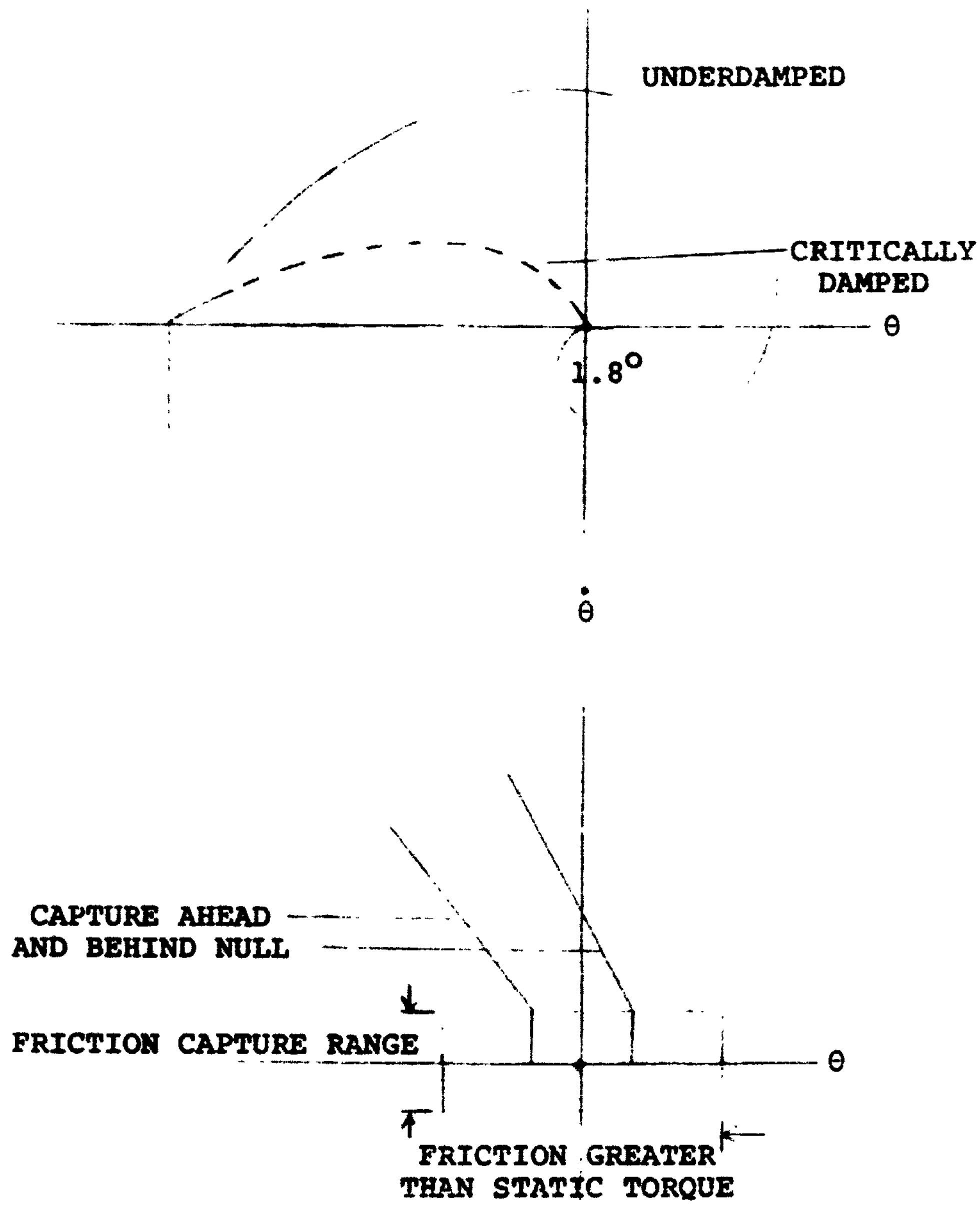


FIGURE I-3. MOTION CHARACTERISTICS

The force equation for the system is:

$$I_E\ddot{\theta} + C_E\dot{\theta} + K_m\theta = T_E$$

where T_E is the developed torque

I_E is the inertia of the rotor and mirror

C_E is the coefficient of viscous friction

$K_m\theta$ is the coulomb friction

The relationship of these factors to modeling a stepper motor includes:

1. The voltage equations of the electrical circuits.
2. The flux linkage relations, including the definitions of inductances.
3. The expressions for developed torque including expressions for stored energy and other energy.
4. The dynamic equations of the rotor.

The modeling of a given system generally includes mathematical formulation of every electrical, magnetic, and mechanical component, then a number of tests of the system are required to empirically insert the basic torque characteristics of the system. In the development of the HIRS, the general characteristics of the system were studied and the electronic drive system designed on the basis of torque and retrotorque, with control of stepping rates for slew control and power control for torque, retrotorque and retorque.

Information was not available for an in-depth modeling of the system. As data became available from final system components, it was apparent that the deviations in step to step position did not easily conform to straightforward torque drive techniques and that some form of damping was required. Tests have shown that for consistent operation, a friction load approximately one-tenth of the maximum torque was required. This provided a baseline for study of the damping function and the possibility of using other types of dampers.

The waveform of the system response to a step input of torque is given in Figure I-4. From this, we can determine the natural frequency of the system and the ratio of damping coefficient critical damping. For the undamped system, this ratio is approximately 0.06. When friction damping is used, the ratio for best operation appears to be about 0.8. Figure I-5 shows the characteristics of damping factors on settling time. A ratio of .90 is considered optimum. The friction system was adjusted for very close to this value.

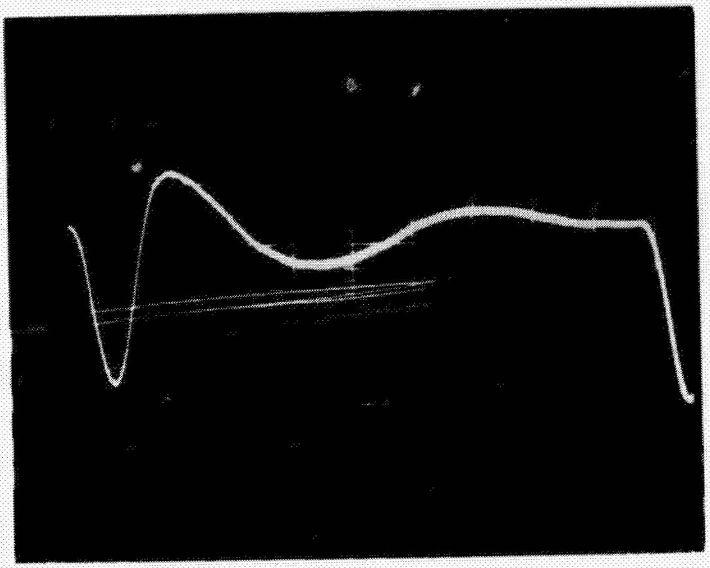
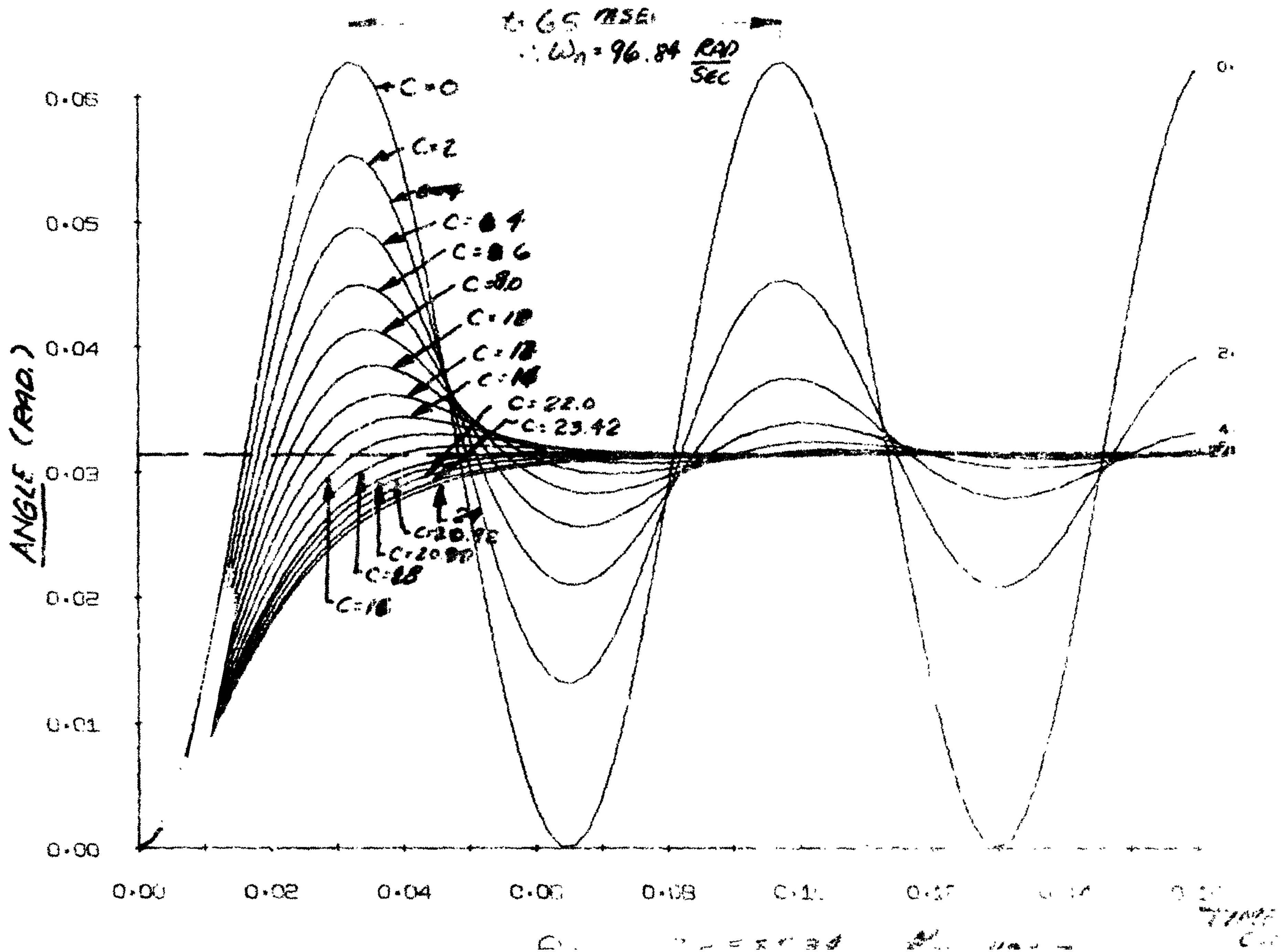


FIGURE I-4. SYSTEM RESPONSE TO STEP INPUT OF TORQUE

20 msec/cm
50 mv/cm



ANGLE (RAD.)
C = 0
C = 2
C = 22.0
C = 23.42
0.06
0.05
0.04
0.03
0.02
0.01
0.00
0.00
0.02
0.04
0.08

Development studies of other damping devices included hysteresis damper, eddy current damper, magnetic particle damper, inertial damper and coupled viscous damper. Laboratory tests on all but the eddy current damper have been able to demonstrate their capability. A summary of the evaluation is given in Table I-2. From this experience, we had to reject the inertia damper as adding too much mass to the system, and the hysteresis and eddy current methods because of the lack of damping at the very low velocities where step settling is the problem. The magnetic particle approach worked well in the laboratory, but the fear of particles escaping from worn seals and entering bearings causes one to reject that approach. The seals are in a constant wear condition and are probably not reliable for 10,000 hours operation.

A passive friction damper is installed in the engineering model and could be designed to reduce the effects of contamination and maintain constant damping through life.

The viscous damping system is limited like the others to a low damping coefficient at low velocities, but there is still some coupling by the fluid even at low velocities. The fluid material and physical shape can be selected for critical damping with an allowable time period. In the HIRS system, this time period is 45 milliseconds to achieve final position within ±1%[1]. The fluid damper characteristic is shown in the tachometer output waveform of Figure I-6. The time to reach settled condition is about 50 milliseconds.

3.0 SLEW AND RETRACE

The motion of the mirror from the end of scan to start of scan is a counter clockwise rotation of 73.8° in 425 milliseconds. After stepping clockwise for the 73.8° twenty times, the mirror slews to the warm target 77.4° in 425 milliseconds then to the cold target 90°, 425 ms), to space (90°, 425 ms), then to start of scan (28.8°, 425 ms). The stepping signals are applied at a high rate in slew mode, with a build-up from approximately 40 pps at start of slew to as much as 160 pps at the midpoint of a 90° slew. At the end of slew, the encoder track provides a signal that stops advance of the winding pulse sequence. The last winding energized is then held in a high energy mode and performs the braking action. As shown in Figure I-1, the constant energizing of one coil will capture the rotor over a range of ±3.6° and bring it back to the

(1) A recent decision by NASA and NOAA permits this time to be extended to 60 milliseconds.

TABLE I-2

DAMPER COMPARISONS

Damper Type	Magnetic Particle	Friction	Hysteresis	Eddy	Inertia	Viscous
Coupling Means	Particles	Rubbing Surfaces	Magnetic Field	Electric	Fluid	Fluid
Active Source	Current	Spring	Current	Current	None	None
Torque at Zero Velocity	Adjustable	High	None	None	None	Seal Friction
Weight Penalty	Low	Low	Low	Medium	High	Medium
Life Limitation	Seals, Particles	Surfaces	None	None	None	Seals
Environment Limit	None	Wear &	None	None	Temp.	Temp.

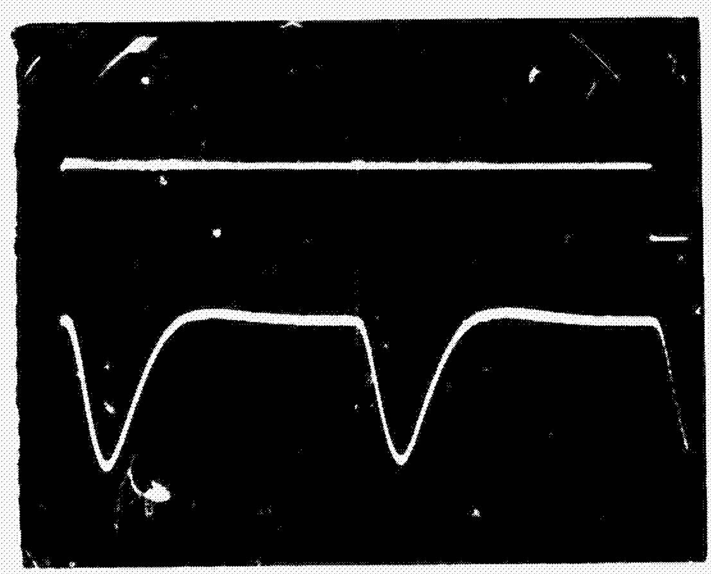


FIGURE I-6. TACHOMETER OUTPUT FLUID VISCOUS DAMPER proper null position. This braking action takes place very effectively, preventing loss of capture at each stop position. The time constant for the capture and settling of the system is approximately 60 msec with no added viscous damping. With the viscous damping, this time constant is reduced to 40 msec. The actual time required for settling is dependent on the velocity of the rotor at the time of capture, the lead or lag angle of the rotor with respect to the winding pulse, and the effect of the next command pulse. In each case where the mirror is driven to a calibrate position, the next command is to hold the rotor at that position, then reduce power during 42 element times.

At the end of retrace, the next command is to step in the opposite direction. This is the most stringent requirement. The settling time is therefore complicated by the fact that the first step coil is energized before the oscillations have subsided. These oscillations are effective in preventing stabilization for the first step, and may still have a degrading effect on as many as four steps. It is for this condition that the viscous damper has the greatest effect, reducing the oscillation decay constant to a low level.

Figure I-7 shows the tachometer output at the end of retrace, indicating the time when the last retrace signal is applied and when the first step signal is applied. The best condition is only a compromise, since the use of viscous damping great enough to reduce the decay time constant to a short interval may also cause retarding of the rotor during slew to the extent that step integrity is lost.

The best condition has been found to be a viscous damping level that allows the decay of oscillation in about three scan element times, as shown in Figure I-7. Repeated tests indicate that the damper is effective in the same manner that an increased torque power level is effective. The probable system compromise will include a combination of viscous damping (electromagnetic aided by fluid) and a small friction load only if the system cannot be made to operate successfully with no external damping assistance.

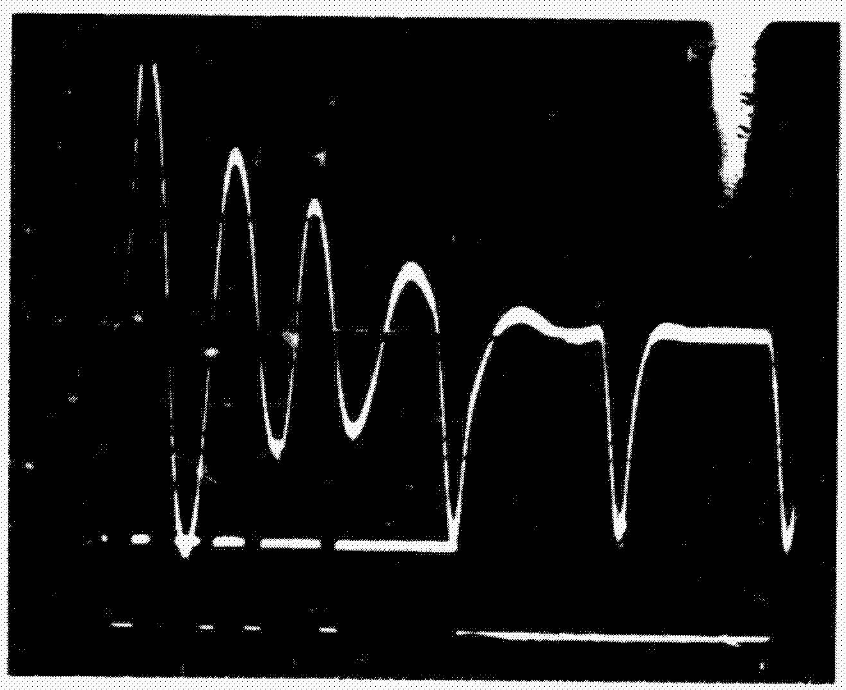


FIGURE I-7. VELOCITY CHANGE AT END OF RETRACE
(50 msec/div)